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Processes for the Fabrication of Isolation Structures

The invention relates to processes for the fabrication of isolation structures for micro-machined sensors in single-crystal surface technology.

For micro-machined sensors in single-crystal surface technology it is necessary to mechanically anchor, on the one hand, release-etched structures, such as spring elements or parts of a plate-type capacitor at the substrate and to electrically isolate them therefrom at the same time.

From the printed publication US 5,930,595 "Isolation process for surface micro-machined sensors and actuators" a process is known by means of which silicon structures defined by deep trenches are etched and are also released at their bottom surface towards the substrate by means of a "release-etch" step. The subsequent lining of these trenches with a non-conducting insulating material, such as silicon dioxide leads to a firm anchoring by means of a surrounding of the silicon structure with the lined trenches on three sides, leaving one side uncovered.

This process, does, however, have a number of disadvantages. The lined non-conducting material in the trench has a growth joint in the centre line. Normally, additional voids are created in the inner area of the joint. These effects result in mechanical instabilities and reliability problems.

Furthermore, the anchoring and isolation structure requires an own and comparatively time-consuming etch step for releasing the bottom surface of the structure towards the substrate, the so-called release-etch step. This step is required once again in the later manufacture of the proper mechanical structure, i.e. it is done twice in the course of the process.

From US 6,239,473 B1 an isolation structure for micro-machined arrangements and a process for fabricating the same is known where at first a deep trench with a high aspect ratio is etched into a silicon substrate and is thereafter lined once again with a thermal or deposited silicon dioxide. Thereafter, the trench that is lined in this manner is completely undercut together with the functional structure such that the functional structure is provided with a verti-

cal, electrical insulation against the substrate in the release-etched part. Here, too, a great disadvantage is that when the trench is lined with silicon dioxide, a growth joint as well as voids are formed in its centre which contribute in a not insignificant manner to the instability of the arrangement.

It is the object of the invention to avoid these disadvantages and to mechanically anchor the release-etched structures at the substrate in a space-saving and reliable way and to electrically insulate them from the same at the same time.

This object is accomplished by processes with the features of claim 1. The embodiment of the invention is in conformity with the features of the dependent claims.

It is the main idea of the invention – instead of lining the trenches – to convert thin-walled silicon into an electrically non-conducting material. This can, for instance, be accomplished by means of a thermal oxidation of narrow silicon ribs released prior thereto by trenches. In the minimal configuration, two trenches (holes) per rib with the required structure depth must be etched for this purpose. The silicon rib between them must be narrow enough to permit its complete thermal through oxidation.

In the course of this oxidation, the silicon is completely converted into silicon dioxide and experiences an approximate doubling of its volume.

With a continuous arrangement of trenches and suitably spaced gaps between them, a continuous isolating oxide structure can be produced over longer distances.

When the ribs are broader, the process of oxidation can also be carried out in several steps, i.e. after a first oxidation step the obtained silicon dioxide is first removed by means of an etch step and oxidised thereafter for a second time. This shortens the process times since the growth of the oxide is a root function of time, i.e. the thicker the oxide the slower the process goes.

In the manner described above, the space needed for the isolation structure becomes very small making it possible to directly accomplish differentially selected capacitive sensors. Furthermore neither growth joints nor voids are formed when this process is used so that the mechanical anchoring of the functional structure in a high quality and with long-term stability

can be ensured. A time-consuming release-etch step is no longer required since the subsequent mechanical structure can be directly anchored at the "oxide pillar".

The invention permits essential improvements in the fabrication of micro-machined sensors in the surface technology on the basis of single-crystal silicon. With this technology, above all inertial sensors for acceleration and rotational speed can be fabricated. In particular, the invention serves the cost-efficient manufacture of acceleration sensors for the use of airbags in motor vehicles.

The invention is described below in greater detail with reference to embodiments and figures. Brief description of the figures:

Fig. 1	shows in a top plan view a section of the substrate after the formation of a pair of trenches.
Fig. 2	shows in a cross-section the arrangement of Fig. 1 along the intersecting line 2-2.
Fig. 3	shows the arrangement of Fig. 1 after the beginning of the process step of the oxidation of the silicon in the trench area.
Fig. 4	shows the arrangement of Fig. 3 along the intersecting line 4-4 in cross-section.
Fig. 5	shows the arrangement of Fig. 1 after the complete oxidation of the silicon between the trenches.
Fig. 6	shows the arrangement of Fig. 5 along the intersecting line 6-6 in cross-section.
Fig. 7	shows the connection of the functional structure with the isolation structure.
Fig. 8	shows the arrangement of Fig. 7 along the intersecting line 8-8 in cross-section.
Fig. 9	shows the electric contacting of an individual structure through a track running via the isolation structure.

Fig. 10 shows the space-saving arrangement of a differential capacitor structure through the alternating contacting of the capacitive fingers.

Starting from a silicon disc as substrate material 1, trenches 12 are etched for fabricating the isolation structures for the functional structures 15. At least two of them are spaced from each other such that a rib 13 of substrate material of a certain width remains between them. The silicon rib 13 must be narrow enough in order to become completely oxidised in the process step of thermal oxidation that follows later. Ideally, the width of the rib lies in the range of smaller 2µm. At first, an etching mask is defined by means of photo-lithographic processes. This is done, for example, by means of a layer of silicon dioxide applied on the surface of the substrate disc which was structured accordingly by means of a photoresist layer or by the photoresist layer itself. Thereafter, the trenches 12 are etched out with a high aspect ratio by means of dry etching. The typical depth of the trenches 12 ranges from about 10 to 30 µm. When necessary, the etching mask is removed at the end. Fig. 1 shows in a top plan view a section of the substrate after the forming of a pair of trenches. Fig. 2 shows the arrangement of Fig. 1 along the intersecting line 2-2 in cross-section.

The intermediate ribs 13 are now converted into silicon dioxide 14 by means of thermal oxidation. Fig. 3 shows the arrangement of Fig. 1 after the beginning of the process step of the oxidation of the silicon in the trench area 14. Fig. 4 shows the arrangement of Fig. 3 along the intersecting line 4-4 in cross-section. The thermal oxidation is carried out under process conditions at typically about 1,100-1,200 °C under wet environment conditions (H_2O).

When the ribs 13 are broader, the process of oxidation can also be carried out in several steps, i.e. after a first oxidation step the obtained silicon dioxide 14 is first removed by means of an etch step and oxidised thereafter for a second time. The silicon dioxide SiO_2 is removed in a wet or dry condition. The multi-step oxidation shortens the process times since the growth of the oxide is a root function of time, i.e. the thicker the oxide the slower the process goes. Fig. 5 shows the arrangement of Fig. 1 after the complete oxidation of the silicon between the trenches 12. Fig. 6 shows the arrangement of Fig. 5 along the intersecting line 6-6 in cross-section.

Now the desired mechanical functional structure 15 is made. At first, an etching mask is made by means of photo-lithographic processes for the trench arrangement 16 which finally defines the configuration of the functional structure 15. Thereafter, the trench structure 16 is etched out with a high aspect ratio in a process step of the dry etching, and finally the side

walls of the trench arrangement are passivated for the subsequent etching step. Following the passivation of the side walls, the etching mask at the bottom of the trench arrangement is selectively opened again. In the subsequent anisotropic etching step, the so-called release etch, the functional structure is so undercut that it is finally connected with the substrate by means of the isolation structure only. Fig. 7 shows the arrangement after the release etch, in particular the connection of the functional structure to the isolation structure. Fig. 8 shows the arrangement of Fig. 7 along the intersecting line 8-8 in cross-section.

Fig. 9 shows the electric contacting of an individual functional structure 15 through a track 18 running via the isolation structure 20. The metallic tracks 18, including contact cuts 19 are made by means of processes which are customary in IC technology, if appropriate, also by using the 2-layer technology. Tracks 18 are defined and structured preferably still before the masking of the functional structures 15.

Fig. 10 shows as a special embodiment an acceleration sensor with a differential capacitor structure. Both the anchoring of the two springs, by means of which the movable structure is hinged to the substrate, and the alternately contacted capacitive fingers are mechanically connected with the substrate by means of a relevant isolation structure which was created in the process in accordance with the invention. The hinge edge of the capacitive fingers is insulated throughout over a great width. For this purpose, a continuous arrangement of trenches 12 with silicon ribs between them was formed in the first step of the described process. In this way a continuous insulating oxide structure 14 can be created over comparatively long distances.

The sequence of the process is summarised once again below:

Forming of the trenches (Fig. 1, 2):

- for this purpose, a lithographic definition of an etching mask (photoresist or SiO_2),
- dry etching of the trenches with a high aspect ratio, typical depth about 10-30 μm,
- if required, removal of the etching mask (in particular of photoresist).

Conversion of the intermediate ribs into SiO_2 by thermal oxidation (Fig. 3-6):

- typical process conditions about 1,100-1,200 °C with wet oxidation (H_2O),
- if necessary, wet or dry removal of SiO_2 and repetition of oxidation.

Formation of the desired mechanical functional structure as well as of the electric contacting:

- metallic tracks, including contact cuts according to the processes customary in the IC technology, also 2-layer technology (Fig. 9, 10),
- dry etching of the functional structure: lithography, etching of the trench structure, side wall passivation, selective opening of the etching mask at the bottom of the trench structure, release etch step (release etching) (Fig. 7, 8).

The invention provides for essential improvements in the fabrication of micro-machined sensors in a surface technology based on single-crystal silicon. With this technology, above all inertial sensors for acceleration and rotational speed can be fabricated. In particular, the invention serves the cost-efficient manufacture of acceleration sensors for the use of airbags in motor vehicles.